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Longitudinal Flight Control Using Nonlinear Controller with Different Altitudes and Weights for Aircraft

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Abstract: A nonlinear approach to the pitch, angle of attack and flight path control problems for the aircraft is presented. Backstopping method is utilized for a control of a globally stabilizing controller. We study the problem of robustness a trajectory tracking controller to a path angle method for a nonlinear longitudinal. In this research we introduce a nonlinear technique backstopping approach to flight control law design and aircraft trajectory tracking. The nonlinear controller designed makes the system follow references in the aerodynamic angles of longitudinal mode using the elevator deflections and the throttle as actuators. Backstopping controller uses the nonlinear equations of motion of airplane. The synthesized of the proposed method is to improve and guarantee the robustness; we therefore tested the control laws in several situations with the analysis of results for several weights and altitudes. Asymptotic Lyapunov stability is ensured for the developed method while robustness is guaranteed to flight control law design and aircraft trajectory tracking. We therefore simulated on MATLAB, the model of the A300 aircraft flying at different weight and altitude. Analysis and simulation results show that the robustness controller is stable and robust in the presence with different altitudes and weights for aircraft.

Keywords*: Flight Control, Longitudinal movement, Nonlineair System, Backstepping, Lyapuov, Robustness*.

1. Introduction

The backstopping control method is a recursive design procedure that links the choice of a control Lyapunov function with the design of a feedback controller and guarantees global asymptotic stability of strict feedback systems. The integrator backstopping control method helps to overcome the limitations of the feedback linearization approach in the control literature. The block backstopping control method is a general backstopping control method with more applicability in the control literature. The adaptive backstopping control method is a modified form of backstopping control method that uses estimates for unknown parameters in the control system for general applications. The robust backstepping control method is an effective backstopping technique for control systems with uncertainties [21].

Flight dynamics is the science of air vehicle orientation and control in three dimensions. The three critical flight dynamics parameters are the angles of rotation in three dimensions about the vehicle's center of mass, known as *pitch*, *roll* and *yaw* (quite different from their use as Tait-Bryan angles) [19].

Aerospace engineers develop control systems for a vehicle's orientation (attitude) about its center of mass. The control systems include actuators, which exert forces in various directions, and generate rotational forces or moments about the aerodynamic center of the aircraft, and thus rotate the aircraft in pitch, roll, or yaw. For example, a pitching moment is a vertical force applied at a distance [6],[19].

An aircraft is a non-linear system. Controlling it is achieved by moving the ailerons, the elevator, the rudder, and the throttle. In this paper, only the elevator is dealt. The throttle is constant, the ailerons and the rudder are null. The control law is designed to explicitly consider the nonlinear aerodynamic forces and moments acting upon the airplane. This is done using a backstopping design, where the control law is recursively constructed, along with a Lyapunov function guaranteeing global stability [23].

Many researches are published in the control of

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aircraft and dynamics model In [24] they are proposed the nonlinear command theory applied to the quadrotor and airplane. In [23] proposed nonlinear flight control is designed by Lyapunov direct method and Matrosov theorem. While in the cited researchs, they are used to decoupled linear models comprised the lateral and longitudinal models. In [25] they are addressing the problem for attitude stabilization of a Quadrotor Helicopter. In [26] they are designed an adaptive flight control using backstepping and neural networks controllers.

In this paper we introduce an alternative for control separation; a backstopping controller is used to achieve global stability with an internal loop controls involving the pitch rate of the aircraft and external loop which includes angle of attack, path angle and pitch angle. A backstopping controller is proposed to solve the pitch angle stabilization problem of the aircraft transportation [3]-[16].

In the literature many techniques of backstopping control design of nonlinear systems are discussed. In this part, our interest concerns backstopping and backstopping robustness for strict-feedback systems. Backstopping is a recursive procedure which breaks a design problem for the full system into a sequence of design problems for lower order systems [2]-[4].

The goal of this research is to simulate a control law able to deal with the aircraft longitudinal dynamics, for all the angles states of the aircraft, with minimal information of the aerodynamic model. The method must be able to make the system seek the references in the aerodynamic pitch and path angle, using as thrust level, actuators and the elevator deflection [15]-[8].

The main objective in this paper is the synthesis of this stabilizing control laws in terms orientation for the aircraft to contribute to the synthesis of a new generation of nonlinear guidance control laws for transportation aircraft resenting enhanced tracking performances. The difficulty of control is mainly due to its complex dynamics, nonlinear multi variable and especially in its operation.

We used several techniques to control nonlinear. All orders are stabilizing designed to ensure the continuation of desired trajectories along a three axes (X,Y and Z) [27].

The proposed controller should guarantee good robustness performances to improve flight control law design and airplane trajectory tracking.

Through numerical simulation, the synthesized of the proposed backstopping controller is study and assesses its robustness; we therefore tested the control laws in different situations with the analysis of results for different weight and altitude.

The rest of the paper is organized as follows. Section 2 presents the nonlinear aircraft model. The backstopping control design is explained in section 3. Robustness of airplane represented in section 4. A numerical simulation is done to demonstrate a robustness of these control laws flight conditions are shown in section 5. Finally, a conclusion is given in section 6.

2. Mathematical Model Aircraft

The model of conceptual aircraft used in this paper is presents a controller for a nonlinear aircraft the general variables are, q,θ,α and γ (flight path angle) and V (airspeed), are represent in Figure 1.[6]-[9].

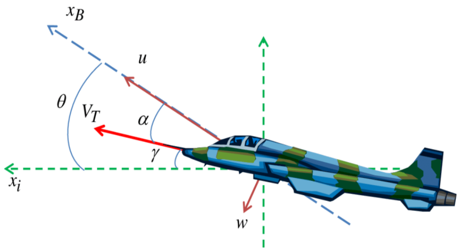

Figure 1. Aircraft Model of Longitudinal Axis

2.1. Equations

$$\dot{V} = \frac{1}{m}(-D + Tcos\alpha - mgsin\gamma) \tag{1}$$

$$\dot{\alpha} = \frac{1}{m}(-L + Tsin\alpha + mgcos\gamma) + q \tag{2}$$

$$\dot{\gamma} = \frac{1}{m}(-L + Tsin\alpha + mgcos\gamma) \tag{3}$$

$$\dot{\theta} = q \tag{4}$$

$$\dot{q} = \frac{M(\delta_e)}{I_y} \tag{5}$$

$\gamma = \theta - \alpha$ is the flight path angle, the following equations express δ_e the elevator deflection. T is the engine thrust control. Finally, D, L and $M(\delta_e)$ are drag, the forces lift aerodynamics and pitching moment. I_y is the inertial moment about y axis in body axes. q pitch angular rate [7]-[18].

$$L = \frac{1}{2}\rho V^2 C_L, \tag{6}$$

$$D = \frac{1}{2}\rho V^2 C_D \qquad (7)$$

$$M = \frac{1}{2}\rho V^2 S\bar{c}C_m \qquad (8)$$

Where ρ is the air density, S is wing surface the reference, $\bar{c}$ is the mean chord and D, L and M are the drag, lift and coefficients of pitching moment.

The following models for the drag and moment coefficients [6].

$$C_D = C_{D_0} + K_1 C_L + k_2 C_L^2 \qquad (9)$$

$$C_m = C_{m_0} + C_{m_\alpha}\alpha + C_{m_q}q + C_{m_{\delta_e}}\delta_e \qquad (10)$$

Where C_{D_0}, K_1, k_2, C_{m_0}, C_{m_α}, $C_{m_q}$and $C_{m_{\delta_e}}$ are pitch aerodynamic coefficients of airplane, and δ_e is the elevator deflection. In this research C_{D_0}, K_1, k_2, C_{m_0}, C_{m_α},$C_{m_q}$and $C_{m_{\delta_e}}$ non dimensional aerodynamic parameters.[19]-[20]

3. Controller Design

The main objective of the controller is to stabilize slow states α, θ and γ.

The objective is to find the elevator expression that corresponds to the desired flight path angle. The approach is to create an error and derivate it in order to zero it out.

The first step is to derivate the flight path angle in order to get the desired angle of attack [8].

$$\dot{\gamma} = \frac{1}{m}(-L + Tsin\alpha + mgcos\gamma) \qquad (11)$$

For the **step 1** is we consider the tracking error:

$$e_\gamma = \gamma - \gamma_d \qquad (12)$$

γ_d is the desired flight-path angle. Its derivative is computed as:

$$\dot{z}_\gamma = \dot{\gamma} - \dot{\gamma}_{ref} \qquad (13)$$

A Lyapunov function for γ is defined by:

$$V_\gamma = \frac{1}{2}e \qquad (14)$$

The system is stable if the derivative of Lyapunov function $\dot{V}_\gamma$is negative:

$$\dot{V}_\gamma = \dot{z}_\gamma z_\gamma \qquad (15)$$

With:

$$\dot{V}_\gamma < 0 \qquad (16)$$

$$\dot{e}_\gamma = -k_3 z_\gamma \qquad (17)$$

Since:

$$\dot{\gamma} = -k_3 e_1 + \dot{\gamma}_d = V_{2d} \qquad (18)$$

For **step 2** we consider a variable:

$$z_{2\gamma} = \dot{\gamma} - \gamma_{2d} = \dot{\gamma} - k_3 z_1 + \dot{\gamma}_d \qquad (19)$$

The derivative of $z_{2\gamma}$ is :

$$\dot{z}_{2\gamma} = \ddot{\gamma} - \ddot{\gamma}_{2d} = \ddot{\gamma} + k_3\dot{z}_1 + \ddot{\gamma}_d \qquad (20)$$

With

$$\dot{z}_\gamma = z_{2\gamma} - k_3 z_\gamma \qquad (21)$$

Such that

$$\ddot{\gamma} = -z_\gamma - k_4 z_{2\gamma} - k_3\dot{z}_\gamma + \ddot{\gamma}_d \qquad (22)$$

$$\ddot{\gamma} = -(k_3 + k_4)z_{2\gamma} - (1 - k_3^2)z_\gamma + \ddot{\gamma}_d \qquad (23)$$

Considering the following Lyapunov condidate function:

$$V_{2\gamma} = \frac{1}{2}z_\gamma^2 + \frac{1}{2}z_{2\gamma}^2 \qquad (24)$$

The derivative equation (36) is computed as:

$$\Rightarrow \dot{V}_{2\gamma} = z_\gamma\dot{z}_\gamma + z_{2\gamma}\dot{z}_{2\gamma} \qquad (25)$$

$$\Rightarrow \dot{V}_{2\gamma} = -k_3 z_\gamma^2 + z_{2\gamma}\left(\dot{z}_{2\gamma} + z_\gamma\right) \qquad (26)$$

With:

$$\dot{V}_{2\gamma} < 0 \qquad (27)$$

$$z_\gamma + z_{2\gamma} = -k_4 z_2 \qquad (28)$$

Thus, the flight path angle:

$$\ddot{\gamma} = \frac{\left(\dot{L}cos\beta - \dot{\beta}sin\beta L + mg\dot{\gamma}sin\gamma + \dot{T}sin\alpha cos\beta + \dot{\alpha}cos\alpha Tcos\beta - \dot{\beta}sin\beta Tsin\alpha\right)V}{mV^2} - \frac{\dot{V}(\dot{L}cos\beta - mgcos\gamma + Tsin\alpha cos\beta)}{mV^2} = -(k_3 + k_4)e_2 - (1 - k_3^2)e_1 + \ddot{\gamma}_{ref} \qquad (29)$$

Thus, the angle of attack becomes:

$$\dot{\alpha} = \frac{\left((-k_3 + k_4)e_2 - \left(1 - k_3^2\right)e_1 + \ddot{\gamma}_{ref}\right)mV^2 + (Lcos\beta - mgcos\gamma + Tsin\alpha cos\beta))}{Vcos\alpha Tcos\beta} + \frac{\left(\dot{\beta}sin\beta Tsin\beta - \dot{T}sin\alpha cos\beta - mg\dot{\gamma}sin\gamma + \dot{\beta}sin\beta L - \dot{L}cos\beta\right)V}{Vcos\alpha Tcos\beta}$$

(30)

4. Robustness of Aircraft

4.1. Robustness results for an aircraft take off law

During research, we were given the opportunity to work on an automatic take- off law. Taking advantage of the generic aspect of the detailed approach we reused the loop part in $\gamma, \alpha\ and\ \theta$ developed for take-off we took the opportunity to assess its robustness to the most influential parameters for flight dynamics: air, mas and density. We therefore simulated on MATLAB, the model of the A300 aircraft flying at mass extremes (90t - 165t) and at air density $(\rho = 0.458312\ {}^{kg}/_{m^2})$.

The synthesized backstepping control law basically takes this information into account to assess its robustness; we therefore tested the control laws in several situations.

Extreme 1: By imposing a weight value (90t) on it while the aircraft is flying at empty weight with an air density value $(\rho = 1.225\ {}^{kg}/_{m^2})$

Extreme 2: By imposing a weight value (165t) on it while the aircraft is flying at maximum take-off weight with an air density value $(\rho = 1.225\ {}^{kg}/_{m^2})$

Extreme 3: By imposing a weight value (90t) on it while the aircraft is flying at maximum take-off and with an air density value $(\rho = 0.458312\ {}^{kg}/_{m^2})$

Extreme 4: By imposing a weight value (165t) on it while the aircraft is flying at maximum take-off and with an air density value $(\rho = 0.458312\ {}^{kg}/_{m^2})$

5. Results

In this section, simulation results of the controllers developed are shown and demonstrate the performance of this control law.

Extreme 1: By imposing a weight value (90t) on it while the aircraft is flying at empty weight with an air density value $(\rho = 1.225\ {}^{kg}/_{m^2})$. Figure 2, 3 and 4 shows the robustness of the angle of attack α, γ and θ in the extreme case 1.

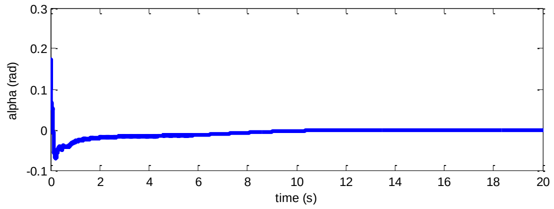

Figure.2. Robustness of the angle of attack α in the extreme case 1

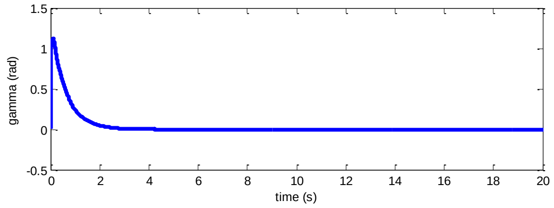

Figure.3. Robustness of the flight path angle γ in the extreme case 1

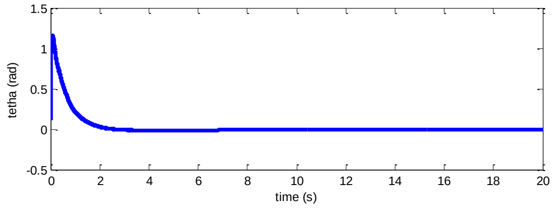

Figure. 4. Robustness of the pitch angle θ in the extreme case 1

Extreme 2: By imposing a weight value (165t) on it while the aircraft is flying at maximum take-off weight with an air density value $(\rho = 1.225\ {}^{kg}/_{m^2})$. Figure 5, 6 and 7 shows the robustness of the angle of attack α, γ and θ in the extreme case 2.

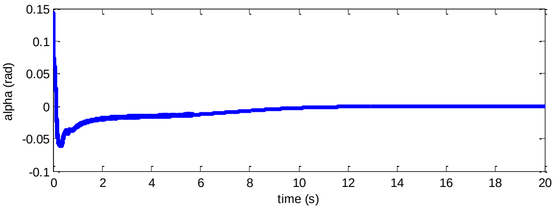

Figure. 5. Robustness of the angle of attack α in the extreme case 2

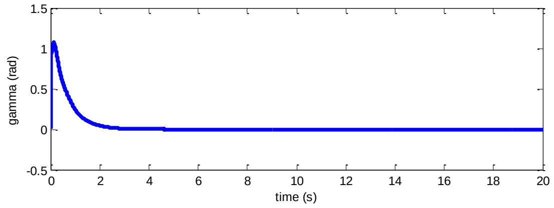

Figure. 6. Robustness of the flight path angle γ in the extreme case 2

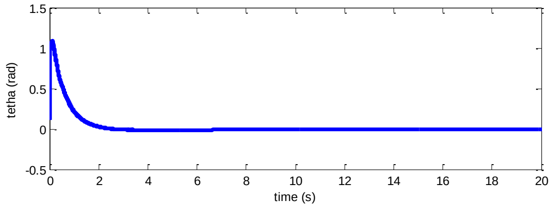

Figure 7. Robustness of the flight path angle θ in the extreme case 2

Figure 8, 9 and 10 shows the robustness of the angle of attack α, γ θ and in empty weight and maximum take-off weight flying.

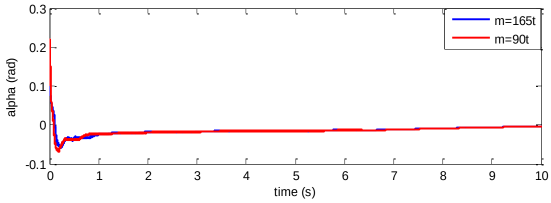

Figure 8. Robustness of the angle of attack α ($\rho = 1.225\ {kg}/{m^2}$)

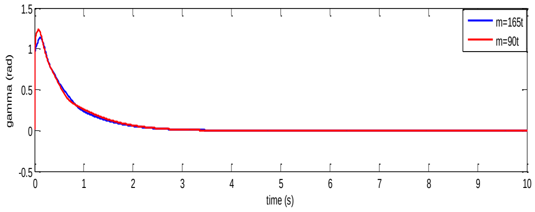

Figure. 9. Robustness of the flight path angle γ ($\rho = 1.225\ {kg}/{m^2}$)

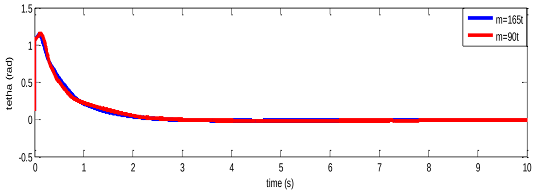

Figure. 10. Robustness of the pitch angle θ ($\rho = 1.225\ {kg}/{m^2}$)

Extreme 3: By imposing a weight value (90t) on it while the aircraft is flying at maximum take-off and with an air density value ($\rho = 0.458312\ {kg}/{m^2}$). Figure 11, 12 and 13 shows the robustness of the angle of attack α, γ and θ in the extreme case 3.

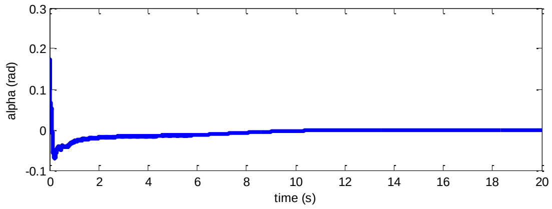

Figure 11. Robustness of the angle of attack α in the extreme case 3

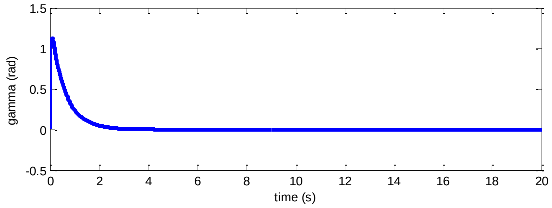

Figure. 12. Robustness of the flight path angle γ in the extreme case 3

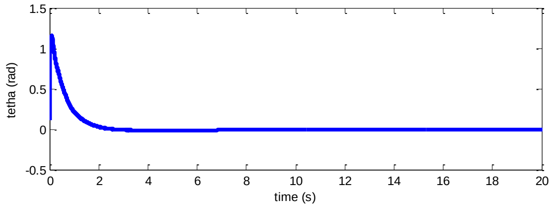

Figure. 13. Robustness of the flight path angle θ in the extreme case 3

Extreme 4: By imposing a weight value (165t) on it while the aircraft is flying at maximum take-off and with an air density value ($\rho = 0.458312\ {kg}/{m^2}$). Figure 14, 15 and 16 shows the robustness of the angle of attack α, γ and θ in the extreme case 4.

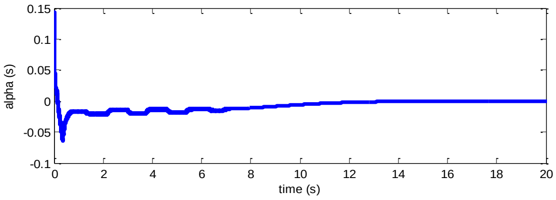

Figure. 14. Robustness of the angle of attack α in the extreme case 4

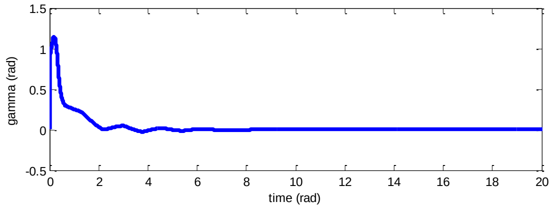

Figure.15. Robustness of the flight path angle γ in the extreme case 4

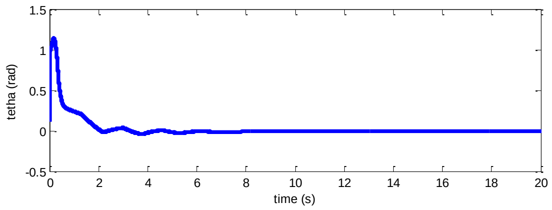

Figure.16. Robustness of the flight path angle θ in the extreme case 4

Figure 17, 18 and 19 shows the robustness of the angle of attack α, γ θ and in empty weight and maximum take-off weight flying

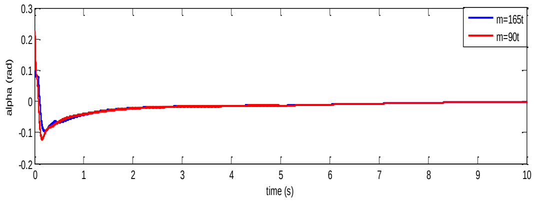

Figure.17. Robustness of the angle of attack α $(\rho = 0.458312\ {kg}/{m^2})$

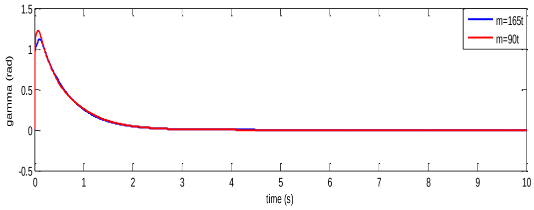

Figure.18. Robustness of the flight path angle γ $(\rho = 0.458312\ {kg}/{m^2})$

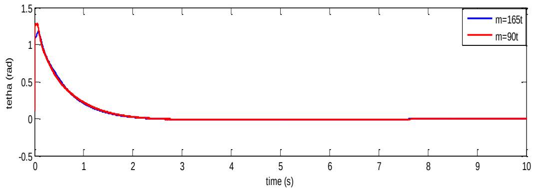

Figure.19. Robustness of the pitch angle θ $(\rho = 0.458312\ {kg}/{m^2})$

Simulation results are presented in the form of a diagram step response of the aircraft figures in **case 1** computer simulation shows tha the imposing a weight value (90t) on it while the aircraft is flying at empty weight with an air density value $(\rho = 1.225\ {kg}/{m^2})$, is robust and best performance.

The ensure the robustness of the airplane to parameter changes of the airplane, is introduce by the feedback signal observation states longitudinal mode, as shown in **case 2 and case 3** By imposing a weight value (165t) on it while the aircraft is flying at maximum take-off weight with an air density value $(\rho = 1.225\ {kg}/{m^2})$ and imposing a weight value (90t) on it while the aircraft is flying at maximum take-off and with an air density value $(\rho = 0.458312\ {kg}/{m^2})$, is acceptable response in this altitude.

In figures in **case 4** the stabilizer mode and robustness of aircraft is given, the outputs are selected as flight path angle, pitch angle and angle of attack by imposing a weight value (165t) on it while the aircraft is flying at maximum take-off and with an air density value $(\rho = 0.458312\ {kg}/{m^2})$, illustrates the response orientation angles track the desired trajectories with an acceptable dynamic.

6. Conclusion

In this paper robust nonlinear method was used to design a control law to be applied in a nonlinear aircraft of longitudinal motion. A backstopping controller was proposed to stabilize and trackα, θ and γ. A controller a six degree of freedom nonlinear flight model is proposed and its stability is analyzed by using the Lyapunov theory. We presented the design a simple adaptive controller for the longitudinal flight dynamics of an airplane that is able to make the aircraft follow references in pitch angle, flight path and angle of attack. The control is achieved by acting the elevator deflection. The throttle is constant, the ailerons and the rudder are null. One of robustness applied to backstepping method is very efficient to control a non-linear system. We study different cases

For different altitude and weight of airplane to improve the performances for control laws. Asymptotic Lyapunov stability is ensured for the developed controller while robustness is guaranteed to flight control law design and airplane trajectory tracking in different weights and altitudes.

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